PERGAMON

Renewable and Sustainable Energy Reviews
4 (2000) 295–313

Renewable
& Sustainable
Energy Reviews

www.elsevier.com/locate/rser

Humankind's detour toward sustainability: past, present, and future of renewable energies and electric power generation

Raphael Edinger[a], Sanjay Kaul[b,*]

[a]*Research Economist at the Institute for Consumer Economics, Hohenheim University, Hohenheim, Germany*

[b]*Associate Professor at the Department of Industrial Technology, Fitchburg State College, Fitchburg, MA, USA*

Received 28 September 1999; accepted 9 December 1999

Abstract

Renewable energies have been the primary energy source in the history of the human race. During the last 200 years, industrialized countries have shifted their energy consumption toward fossil fuels. Contemporary electric power generation is based on non-renewable resources such as oil, coal, and nuclear power. New efficient and cost-effective small-scale renewable energy generation options are commercially available today. Market distortions are to be overcome in order to make renewable energies cost-competitive in today's economic environment. Social, environmental and also economic reasons will reverse the worldwide primary energy use back to renewables and thus reapproach a sustainable economic system based on traditional and new high-tech technologies. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Historically, the world energy supply was based on renewables. Wood was used for cooking, water and space heating. Water powered mills were found

* Corresponding author. Tel.: +1-978-665-3050; fax: +1-508-343-3043.
E-mail address: skaul@fsc.edu (S. Kaul).

1364-0321/00/$ - see front matter
PII: S1364-0321(99)00017-9

throughout Europe, especially in Southern Germany and Switzerland, while wind mills belonged to the scenery of the Netherlands and Northern Europe. The first renewable energy technologies were primarily simple mechanical applications and did not reach high energetic efficiencies.

Industrialization changed the primary energy use from renewable resources to sources with a much higher energetic value such as coal and oil. In the early days, pollution by the burning of fossil fuels was not a critical issue. Due to their superiority by providing cheap power at any location independent from the availability of wind or water sources, they quickly became the most used energy source. The emerging industry did not pursue the technical improvement of technologies such as small-scale hydro and wind power any further. The promise of unlimited fossil fuels was much more attractive and rapid technical progress made the industrial use of oil and coal economical. Renewable technologies like water and wind power probably would not have provided the same fast increase in industrial productivity as fossil fuels did.

Today's economies of industrialized nations are primarily based on the use of fossil energy resources. Developing countries are about to follow the example of industrialized nations and thus intensifying their use of energy to increase their economic output. After the oil crises, the industrialized nations managed to unlink economic growth from increasing energy use. However, they still consume the largest share of the global natural resources and contribute significantly to the world's emissions of greenhouse gases and other pollutants. With developing nations such as India and China accelerating their economic uprising, the global use of fossil fuels could have significant impact on the global climate and the biosphere.

The electric power sector is one of the major industries using fossil fuels to generate electricity. Increasing environmental concern is linked to fossil fuels used for power generation. The greenhouse effect is related to augmenting carbon dioxide emissions in the world's atmosphere, and many other pollutants that are emitted by burning coal and oil have negative environmental impacts. These negative effects which are mainly not being internalized into the price of fossil resources are not restricted by national boundaries, but affect neighbor countries as well as states far away from the polluting source.

Technical efficiencies and economic cost-effectiveness of modern small-scale renewable power generation technologies have improved impressively over the last decades. This paper examines the present status of electric power generation and indicates a way to shift to a more sustainable energy system using modern, highly efficient renewable energy technologies. While economic factors are currently imposing obstacles against the market penetration of renewable energies, empirical data and theoretical concepts are presented that offer solutions to make renewable technologies cost-effective alternatives to fossil fuel electricity generation.

2. Microeconomics of renewable power generation

2.1. The decline of economies of scale in electricity generation

As technology and sciences advanced in the 20th century, we saw the rise of a promising technology. Nuclear power was regarded to be the solution for future energy demand, providing cheap and nonpolluting electricity for a steadily growing human population. In the 1980s, however, nuclear power generation faced declining acceptance due to the yet unsolved question of final nuclear waste disposal and the public perception of the dangers of this technology. The accidents in the U.S. power station at Three Mile Island and at Chernobyl in the former Soviet Union manifested the operating risks of nuclear power plants. After the end of the cold war, an increasing number of critics pointed to the dangers of nuclear energy such as technical security, disposal of radioactive waste, and terrorism.

But it was not the concerns of a more and more ecologically and security aware population that marked the turning point in nuclear energy investments which were made by a highly vertically integrated monopolistic industry. Rising construction and production costs of nuclear power plants, the decline of fossil fuel prices, and technical progress in gasturbine technologies, as well as the fear of non-recoverable sunk costs in a deregulated and more competitive market stopped the rise of nuclear power production [1]

Until the 1980s, economies of scale reached by large power plants up to 1000 MW continuously decreased the average cost of electricity generation. Advancements in gas turbine technologies, however, reversed this trend (see Fig. 1) [2]. Combined-cycle gas turbines reach maximum efficiencies at power plants as small as 400 MW, and aero-derivative gas turbines can even be efficient at 10 MW [3]. Although still more expensive than fossil fuel generation, renewable energies show advantages due to their modular character and their ability to add new capacity incrementally and adjustably to the current energy demand.

2.2. The concept of distributed electricity generation

Today's renewable technologies are high-tech technologies and mostly originated from the aerospace or military industry. Rotors of the wind generators are based on scientific research on airplane propellers, while the first solar cells were created to power space satellites in the utmost remote location where high reliability and durability were crucial and fuel costs extremely expensive. After having performed in satellites, the photovoltaic technology was applied to power remote telecommunication applications. As PV prices declined rapidly, photovoltaic became an option for powering residential housing located off the grid and are today at the turning point of becoming cost-effective even for grid-connected applications [4]. Hawaii is one of the top-five niche markets for photovoltaic systems with break-even system prices reaching up to more than U.S. \$7 per watt. California, Arizona, New York, and Massachusetts combine good

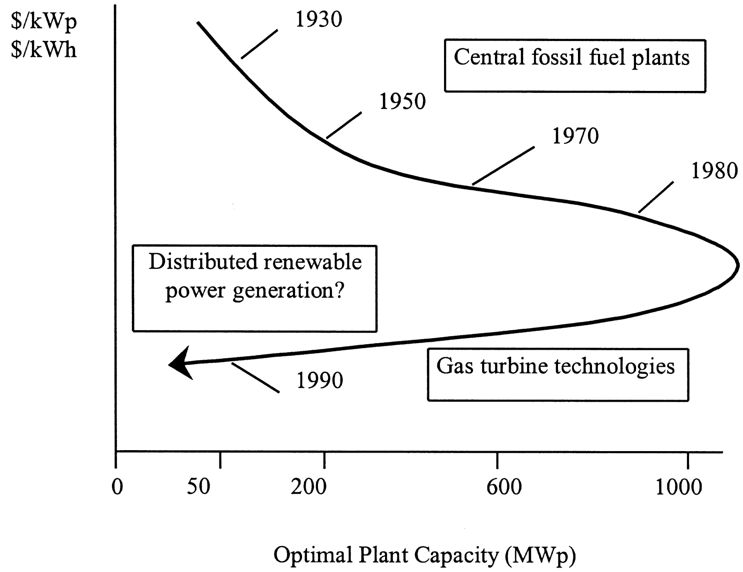

Fig. 1. Optimal plant size in terns of cost-effectiveness and energy efficiency (Source: Edinger and Kaul, Renewable resources for electric power. Prospects and challenges Westport 1999, Quorum Books: p. 76.

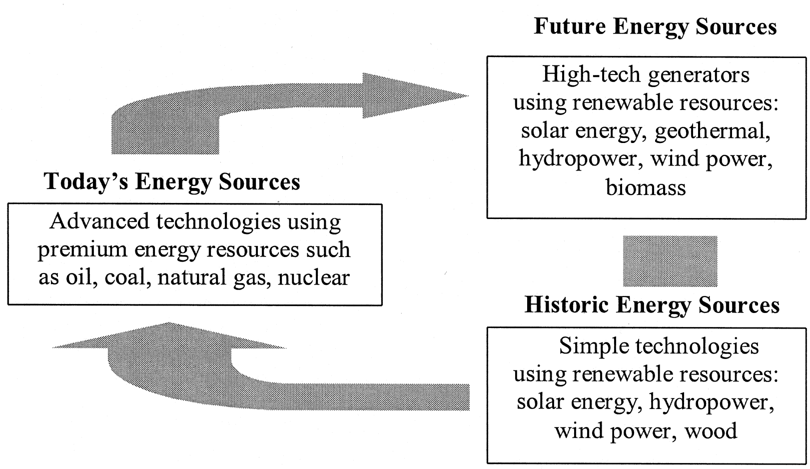

Fig. 2. Primary world energy sources over time: Humankind's detour towards sustainability. (Source: Edinger and Kaul, Renewable resources for electric power. Prospects and challenges (Westport 1999, Quorum Books: p. 136).

insolation levels with high residential electricity rates, which leads to photovoltaic system break-even prices exceeding U.S. $4 per watt. These cost levels are quite close to today's PV system costs, depending on renewable tax incentives and the utility's green pricing programs as well as its commitment to procure photovoltaic systems strategically and thus purchasing larger quantities for lower unit prices.

Small wind generators and microhydro technologies have become even more cost-effective than photovoltaic technologies. While microhydro generation is naturally bound to natural water resources, it is the most economical renewable alternative and can compete with the cost of fossil fuel power generation. The joint implementation of these renewable power generating options in locations where they are economical would change the current centralized structure of the electric power industry to a more decentralized and distributed power supply system [5].

The Interstate Natural Gas Association of America Foundation (INGAA) defines Distributed Generation as "any small scale power generation technology that provides electric power at a site closer to customers than central station generation, and is usually interconnected to the transmission or distribution system". In the future this definition is to change from "is usually interconnected" to "which may or may not be interconnected" [6]. An energy system based on renewables combines many small-scale renewable energy sources such as solar energy, water and wind power, geothermal and biomass (see Fig. 2).

Distributed generation can be more reliable than central power supply. Major outages are frequently experienced in developing countries, but also in industrialized states such as the USA. They would be less likely to occur in a system of a broad range of decentralized power generators. Critics argue that small power producers could deteriorate the quality of the electricity delivered by the central grid that is necessary for many of today's high-tech appliances such as computers. However, performance studies indicated that the quality of photovoltaic power measured by the purity of the sine wave pattern proved to be better than the one of the utility grid at the end of the distribution line [7].

Renewables are not as easy to handle as conventional energies. Fossil fuels could easily be stored and used when needed. Renewable resources are mostly bound to natural events such as a varying insolation which is dependent on the time of day, season, or rainfall. Until the promising technologies of hydrogen and other storage mediums will eventually be marketable, it is often viable to use modern fossil fuel technologies such as gas turbines or, in the near future, fuel cells as a back-up for periods of higher energy needs. Gas turbines are already available at cost-effective prices and in modular sizes. Fuel cells promise high efficiencies, but are still in the R and D phase and therefore quite expensive [8]. The research conducted by automobile companies to make fuel cell vehicles viable for mass production promises to provide synergies for the electricity market. The price target of mobile fuel cell components necessary for automotive applications make heat and electricity cogeneration in stationary fuel cell systems cost-effective even before cost-competitiveness with internal combustion engines in the transportation sector will be achieved.

Wind energy gains growing market shares in Northern European countries such as Denmark, the Netherlands, and Germany, as well as in India and China. U.S. installations of wind generators slowed down due to further declining fossil fuel prices and restricted state incentive programs [9]. For remote locations, but also for grid-connected applications, the combination of wind power and photovoltaics is feasible because of their nicely fitting peak profile over time. The high electricity output of PV in summertime is supplemented by the higher performance of wind generators in autumn, spring and winter when insolation is lower, yet wind speeds increase. Systems consisting of photovoltaics, fuel cells and hydrogen technologies are a viable combination to overcome storage problems and provide uninterrupted and reliable power in a decentralized method, not relying on a central power grid. Also, a hydrogen fuel cell energy system could be based on renewable resources and thus avoid toxic and greenhouse gas emissions. Hydrogen, either in its gaseous or cryogenic form, can be produced via electrolysis from regenerative power (wind or water power) or directly from surplus photovoltaic electricity as one form of solar energy.

2.3. The key issue: prices

2.3.1. Photovoltaics as an economic viable renewable energy option

In spite of the unequal subsidizing of renewable and fossil energies, research and development of renewables has come far since the early seventies. Between 1975 and 1995, the world price for photovoltaic modules declined from more than 80 U.S.$ per watt to about 4 $ per watt today [10].

Proactive U.S. utilities are looking for new markets and new ways to attract customers in a future competitive environment. A major player is the Sacramento Municipal Utility District (SMUD) in California. SMUD sees PV as already cost-competitive in grid-connected residential rooftop PV systems in its service territory and seeks to aggressively bring down the cost. Its customers are offered to participate in the SMUD PV Pioneer Program. SMUD is installing grid-connected rooftop PV systems for a monthly green fee of an additional 4 U.S.$, which is an approximately 15% premium to the customers' utility bills [11]. The PV Pioneer Program proved highly successful and exceeded expectations by far with about 500–1000 customers volunteering each year for the approximately 100 PV Pioneer systems available annually.

Stimulating the market is an important challenge for renewable energies. Waiting for renewables to become cost-effective in a world of distorted energy prices proved to be a futile battle due to the insufficient internalization of external effects such as social and environmental impacts of fossil fuels [12]. The Sacramento Municipal Utility District developed a strategic concept to actively bring down photovoltaic system costs to a cost-effective level. This Sustainable Orderly Development (SOD) strategy improves the cost-effectiveness of PV technologies through reliable long-term contracts with the photovoltaic industry. Larger cost-effective utility markets are necessary to accelerate commercialization through mass production of PV systems and to make manufacturers independent

from subsidies. SMUD's long-term contracts with the PV industry have reduced SMUD's solar system costs and made it the most cost-efficient one under today's utilities investing in grid-connected residential PV systems. SMUD expects its PV system costs to decline below $ 3 per watt in 2002, which would make PV a cost-competitive option for the electricity retail market where prices reach up to 10 cents per kWh today [13]. In the wholesale market, PV is only feasible if industrial or commercial companies want to use their own generation or usage of renewable energies as a marketing argument and in turn, hope to attract environmentally conscious customers.

2.3.2. Microeconomic analysis tools for renewable energies

Conventional investment calculations did not address the specific advantages of renewables such as lower financial risk and independence of changes in fuel price or new environmental legislation.

The economic evaluation of renewable and fossil fuel power generation requires modern methods of cost calculation in order to address renewable energy specific features. The "Risk Management Approach" quantifies the economic assets of renewable technologies in regard of uncertainties in investment decision making.

Renewables have a variety of advantages due to their modular and small-scale character, as well as, due to their independence of fuel other than abundant renewable resources such as solar radiation, hydro, and wind power. Case studies using risk management methods to evaluate least-cost alternatives have shown that renewables can be cost-competitive with fossil fuels or nuclear power [14].

Renewables have advantages, as far as the financial risk of capital investments in new power generating facilities is concerned. Fluctuating fuel prices affect the operating cost of fossil power generation, while renewable energies such as water, solar, and wind power are independent of volatile fuel prices.

Generally, electric utilities are confronted with demand uncertainty. Expectations of high demand growth have lead to over-capacities and suboptimal allocations of resources after the energy crises. Uncertain demand in a deregulated environment sets any long-term capital-intensive investment of central power plants at a high risk. The modular character of small-scale renewable technologies overcomes the risk of sunk costs when future demand is unpredictable.

Utility investments in central power stations face various risks. Capital cost may increase due to cost overruns and project delays. Fossil-fueled central power stations are usually built for long lifetimes (30 years or more) but could become economically obsolete due to technological progress before costs are recovered. Operating costs can increase by future environmental regulations for fossil-fueled power plants to satisfy stringent emission standards. Outages of central power plants are very expensive, while a multitude of small-scale renewable generators is much less likely to fail at the same time.

Deregulation is about to transform the vertically integrated electricity industry into a more competitive market. This process is highly uncertain and bears a variety of risks in regard to the new market structure. Consumer choice in the

retail and wholesale market could favor renewable energies as a clean power generating technology.

Besides the risk mitigating aspects mentioned above, renewables could also contribute cost-effectively to a diverse and distributed energy system. As utilities like PG&E have experienced, renewable energies often are a least-cost alternative to upgrading existing electricity lines and are preventing grid losses by using resources nearer loads. Cutting peak loads and improving reliability is an important economic advantage of renewable technologies such as photovoltaics. PG&E experienced benefits worth 1.8 times the value of avoided energy and capacity by distributed resources using renewable technologies such as photovoltaics at its Kerman substation [15].

Another approach to compare fossil fuels and renewable energies is the "Total Fuel Cycle Analysis". This analysis reviews all stages of energy mining, processing, transport, storage, generation, end use, and waste disposal. At each stage of the energy production process, all internal and external costs, i.e. costs that are not included in the market price, are considered.

The complexity of this approach as well as the internalization of external effects of fossil energies prevented the total fuel cycle analysis to become an instrument for microeconomic decisions. On the macroeconomic level of national and international energy planning and policy making, however, the Total Fuel Cycle Analysis gains merits to quantify the real cost of renewable and fossil fuel technologies [16].

2.3.3. Micro-gasturbines versus renewable electric power generation

Natural gas has become a major hope for changing toward a more environmentally friendly electric power system. The incentive to shift from coal or oil fired electric power stations to modular gas turbine plants has been a rather economic than an ecological one, though. Today, natural gas prices are at relatively low levels. Natural gas promises to be an additional energy source for industrialized economies in order to broaden their energy basis and reduce the countries' dependence on crude oil imports.

While gas-powered electricity generation is energetically more efficient and causes less toxic and greenhouse gas emissions than oil or coal fired power plants, natural gas is an exhaustible and limited fossil resource. Estimates vary, but predict that global natural gas resources will last one or two decades longer than oil resources.

However, it is not only the electricity industry that is eager to change from other fuels to natural gas for its economic advantages. Residential space heating, industrial process heat and cogeneration as well as the automotive industry have also started to set their focus on this comparably cheap and clean energy carrier. Taken into account the increasing energy demand (dynamic energy demand and supply assessment) for large developing nations such as India and China as well as the augmenting use of natural gas in various industry sectors (transportation, households, industry etc.) lead to the conclusion that this enormous increase of

natural gas consumption in the coming decades may diminish natural gas resources much faster than anticipated.

Natural gas, too, is a type of fossil fuel and thus limited. Predictions for crude oil supply and demand may therefore also be transferred to the outlook of natural gas. The International Energy Agency (IEA) has examined the situation and development of global crude oil in its "World Energy Outlook, 1998" [17]. Three scenarios (ultimate conventional oil reserves of 2000; 2300 and 3000 bio barrel) identified that as soon as in 2007 (2010 and 2019, respectively), the OPEC Middle East countries' share of global crude oil supply will exceed the Non-OPEC countries' share. Latest as soon as OPEC covers more than 50% of the world crude oil market, the Middle East countries will have the possibility to substantially influence market prices.

Germany used to experience increasing gasoline prices during the summer vacation period and declining prices afterwards. In 1999, the comparably high price level of gasoline did not decrease in autumn. This may be due to the fact that today, the OPEC countries find it easier to persist on higher world market prices since they now again cover 30% of global crude oil supply. In the first oil crisis in winter 1973/74, the OPEC countries already had reached a market share of 30% and tried to significantly increase crude oil prices. This attempt failed in the long run since Western oil companies were able to shift towards new oil fields in the North Sea, in Alaska and in Canada [18]. Today, the rough competition between major oil companies for access to existing and expected oil fields suggests that it may not be as easy as in the seventies any more to find new large oil reserves.

While we may not be in danger of running out of oil or gas in the short run, this development could lead to a political rather than a material shortage of our currently most important energy resources. Volatile and thus hardly predictable oil and gas prices in the coming decades add to the attractivity of electric power generation based on renewable resources which are comparatively expensive still, but not as sensitive to short-term price increases that are based on political shortage reasons. It may also be mentioned that today's major oil producing countries, located primarily in the Middle East, do not coincide with those with the largest reserves of natural gas, located in the Russian territories. The competition between these countries and their energy products may lead to cheap prices for both crude oil and natural gas in the short run, thus accelerating the consumption and decline of fossil fuel reserves, until sudden price increases follow as soon as this head-to-head race between natural gas and crude oil sales comes to an end for reaching the limits of extraction and production.

3. Macroeconomic issues of renewable power production

3.1. Market distortions through externalities and state subsidies

In a competitive market, renewable energies have to compete with the prices of

fossil fuels. However, the actual prices of oil, coal and nuclear fuels hardly represent the real cost of these technologies. Nature itself is not given a price in today's economy [19].

Renewables are handicapped in regard of unequal state subsidies for fossil and renewable technologies. Although modern renewable technologies such as photovoltaics have already been developed and in use for several decades, the U.S. and most of the other industrialized countries still subsidize fossil fuel technologies much more generously than renewables. Between 1978 and 1991, more than 70 billion U.S. tax dollars have been spent for nuclear research, and another 25 billion U.S. dollars for fossil fuel technologies. Although renewables such as PV had proven to be technically feasible, they were granted less than 10 billion U.S. dollars which equals 9% of the total government research and development spending in International Energy Agency member countries [20]. This meant a steady disadvantage in the development and marketability of new high-tech renewable technologies.

In Europe, the German Kohlepfennig is an incentive to make German coal cost-competitive with cheaper international coal. The tax incentives and subsidies for fossil fuels have slowed down the development of renewable energies and marked the path of our energy systems in the direction of a preeminent use of fossil fuels. State subsidies veil the real price of fossil power generation and are obstacles towards a sustainable development of the world's economies. If external effects and subsidies for fossil fuels had been taken into account, renewables could have already been cost-effective in many applications for years and hence would have changed the structure of today's centralized electricity system.

3.2. New employment opportunities

Creating additional employment opportunities becomes an important issue in industrialized countries where unemployment is a social as well as an economic problem. According to empiric studies, renewable technologies could contribute to more jobs than our present energy system based on fossil fuels. Renewable energies can create new and additional jobs in the research and development, manufacture, construction, financing, operation, and maintenance. A study by the New York State Energy office found that wind power created 66% more total jobs than natural gas and 27% more total jobs than coal. Construction of a new coal or nuclear power plant and its power production requires about 540 workers, while a solar thermal facility creates 1250 jobs and a wind farm provides 2700 jobs respectively [21]. Further research is needed to assess the impact on net employment of changing national energy systems from fossil fuel to renewable technologies.

4. International and U.S. legislation on sustainable technologies

4.1. International legislative decisions and policies regarding sustainability

The United Nations Conference on Environment and Development at Rio de Janeiro from 3 to 14 June 1992, also known as the "Earth Summit", discussed the global economy and analyzed conditions to achieve a long-term oriented economic and ecological equilibrium. This U.N. convention was a first multinational conference advocating the path towards a sustainable world economy. The Rio Declaration proclaimed 27 principles to be implemented in order to reach this goal [22]. States were assured to have the sovereign right to exploit their own resources but were also bound to their responsibility towards the environment. The concept of sustainability respects the rights of present and future generations and tries to prevent today's economies from exploiting the world's resources at the expense of future needs.

Overcoming poverty and warfare as well as providing education and equal rights to all people are seen as crucial prerequisites to protect the health and integrity of the Earth's ecosystem. The declaration of Rio also encouraged states to enact effective environmental legislation and advocated the internalization of environmental costs.

Five years later the implementation of Agenda 21 was examined and discussed at the Earth Summit + 5, a U.N. conference on sustainable development held in New York on June 23 to 27, 1997. Today's global economy was reckoned to be far from meeting the goals of Rio. Developing countries still struggle against poverty and deteriorating terms of trade. Countries in transition, such as China and India, expect high population growth and a launching industrialization process that could lead to environmental impacts of a magnitude not yet experienced.

Industrialized countries did not provide a very convincing battle against the negative impact of economic growth on the environment either. Although one of the most energy-efficient countries, Germany is far from reaching its self-set target of carbon dioxide reduction in industrial production. In comparison to the U.S., however, the German per-capita energy use is significantly lower than the U.S. equivalent. The reason for this can easily be found in different consumption patterns due to substantially higher energy prices through European taxation practices [23]. While advocated by several nations with great emphasize, the U.N. conference in New York did not settle an agreement on reducing greenhouse gas emissions such as carbondioxide on a fixed level within a certain time frame.

In 1997, the Kyoto Conference, Japan, put the subject of reducing global greenhouse gases on the political agenda again. The Kyoto Protocol determined reduction targets for carbon dioxide equivalent emissions for industrialized countries. The merits of Kyoto are the quantified national targets to be reached on 1990 levels. Kyoto's weakness consists in the missing sanctioning instruments to punish a failure in reaching these national emission reduction targets. Additionally, the Kyoto protocol has not been ratified by all participants so far.

Nonetheless, the spirit of Kyoto has laid the foundation of subsequent national emission legislation as well as on self-commitment promises of governments and industry (e.g. the European vehicle manufacturers agreement to reach a 140 g/km carbon dioxide fleet emission level).

4.2. U.S. legislation concerning renewables

In the history of the U.S. electric utility industry there have been numerous laws and acts addressing the use of renewable resources. This paragraph introduces important legislative decisions influencing the historic and future role of renewables in the electricity market [24].

The Public Utility Regulatory Policies Act (PURPA, 1978, Public Law 95–617) was passed in response to the unstable energy climate of the late 1970s and promoted the conservation of electric energy. PURPA also created a new class of non-utility generators, small power producers (SPPs), from which, along with qualified cogenerators, utilities are required to buy power. The rate of these power purchases was set at the utility's own incremental or avoided cost. For this reason, the small power producers received payments at prices that are substantially higher than today's wholesale power prices. The SPPs usually used renewable resources such as small hydro and wind power and increased the share of distributed energy generation remarkably. Renewable capacity other than already established hydroelectric plants has grown from almost zero in 1980 to about 10,500 MW in 1994, according to data from the National Renewable Energy Laboratory (NREL) and the Edison Electric Institute [25].

The Energy Tax Act of 1978 (ETA, Public Law 95–618) encouraged investment in cogeneration equipment and solar and wind technologies by allowing a tax credit on top of the investment tax credit. This was a first attempt to address the problem of fossil fuels not reflecting the real cost of their use. It was now possible to subsidize and promote renewable energies directly through taxation practices. Renewable energies are often not cost-competitive in traditional accounting practices since they require higher capital investments than fossil fuel technologies. However, renewable energies have non-traditional benefits since they do not share the problem of toxic emissions. Government expenditures for health care and ecological repairs are necessary to compensate the damages to the environment and human health caused by the burning of fossil fuels. Taxation is an effective method to overcome discrimination against renewable energies by giving nature a price and adding this cost to the price of non-renewable energies, thus minimizing environmental and social damages before they are produced.

The Clean Air Act Amendments of 1990 (CAAA, Public Law 101–549) focussed on reducing emissions of electricity generation drastically. The goal of the legislation was to reduce annual sulfur dioxide emissions by 10 million tons and annual nitrogen oxide emissions by 2 million tons from 1980 levels. Generators of electricity were held responsible for large portions of the sulfur dioxide and nitrogen oxide reductions. Renewable electricity generation

technologies apparently do not contribute to any of the addressed emissions that are deteriorating the quality of the atmosphere.

The Energy Policy Act of 1992 (EPACT, Public Law 102–486) created a new category of electricity producers, the exempt wholesale generators, which are exempted from PUHCA restrictions. This accelerated the development of non-utility electricity generation providing new access opportunity to a wider range of power producers, not necessarily using renewable resources. However, the Energy Policy Act of 1992 contains various environmental provisions with respect to global warming issues and advocates the development of renewable energy technologies that contribute little to smog, acid rain, or greenhouse gas emissions [26]. The Energy Policy Act instituted a permanent 10 percent energy tax credit for solar and geothermal projects and established a Renewable Electricity Production Credit of 1.5 cents/kW h over 10 years for electricity generated by using new wind turbines and selected biomass technologies [27].

California's Assembly Bill 1890, [28] (AB 1890, enacted on September 23, 1996) deregulated the electricity industry and set up funding and allocation guidelines for support of renewable electricity generation technologies. AB 1890 provides $540 million from investor-owned utility (IOU) ratepayers over the period 1998 through 2002 to support existing, new, and emerging renewable electricity generation technologies. Due to federal legislation practices, the California Public Utility Commission (CPUC) promotes utility investments in renewable energies through quantity mandates rather than price mandates [29].

The fast evolving process of electric restructuring and deregulation may increase the necessity of further U.S. legislation protecting renewable power generation against short-term energy prices that are set under internal costs.

5. Reshaping the energy market

5.1. Renewables in a liberal electricity market

5.1.1. Public support for non-polluting energies

Public support is growing for renewable technologies. Public opinion polls in the U.S. conducted since the 1970s have shown a preference for energy conservation, energy efficiency, and renewable energy resources augmenting from less than 40% to more than 70% of the participants in recent surveys [30]. As market studies of U.S. utilities indicate, there is a significant number of customers who are even willing to pay higher prices for clean energies, although the restructuring debate has often leaned in the direction of how to decrease prices. This approach did not pay attention to the quality component of clean renewable energies. Green pricing programs in a still regulated market have tried to take into account consumer preferences for clean power generation. In a liberalized market environment, electric power can be marketed and branded as any other commodity. Customers with a preference toward environmentally friendly power generation have the opportunity to purchase green power, whereas customers

preferring cheap electricity may choose to sign a contract with the electric utility that offers the cheapest electric rate.

5.1.2. Marketing and branding

The creation of electricity brands by marketing electrons with attributes such as low price, high reliability, or environmental friendliness in a competitive market offers alternatives to satisfy specific customer needs [31]. In a restructured electricity market, utilities are able to use marketing instruments in order to address distinctive consumer groups and hereby segment the electricity market. The price of electricity is but one aspect to be promoted. Utilities and power marketers also assess the quality of electric power service such as reliability and availability as well as environmental friendliness to acquire new customers or prevent them from switching to another electricity supplier. Creating utility-customer relationships offers a competitive advantage to any utility able to have customers sign long-term energy service contracts.

5.2. Adjusting energy demand

5.2.1. Load management

In the near and mid-term future, renewable energies will not be able to provide the amount of power modern industrialized nations consume today, nor the electricity that would be necessary for developing countries to reach the industrialized nations' level of energy consumption. If we approach this problem from the consumer side, however, renewables are indeed capable of producing a remarkable share of the global energy demand.

Electricity generated by photovoltaic panels is very expensive, but it also reflects the real value of this energy form. Electric power is the most sophisticated form of energy and can be used for a broad array of applications. Since it also is the most costly form of energy, an economic analysis has to determine where other forms of energy could replace electric power providing energy services more efficiently. Consumers demand the services that energy provides, such as space and water heating, cooking, or the music provided by a radio. They do not demand energy or electricity itself [32].

Transforming heat into electricity and transmitting this electric power over long distances is connected with high energetic losses. Using electric current to produce heat for cooking or space heating or cooling indicates an energetically inefficient use of electricity. The low cost of power generated by fossil fuel plants has made this inefficient use of energy economically cost-effective.

An energy system based on renewable resources is not feasible without reducing the consumer load side by energy efficiency efforts and by using the appropriate energy form to produce energy services. The question is not how to meet today's electricity demand with renewable technologies, but how to adapt our energy demand to a feasible amount of power that could be provided by renewable resources. Load management must be the first step in reorganizing the energy system, and it always is the most cost-effective alternative to cut down the load

side first before investing in renewable technologies. An analysis of an average remote photovoltaic home calculated energy consumption reductions from 7377 W h to 3898 W h per day by improving energy efficiency in three appliances only: compact fluorescent lights replaced incandescent lights, an efficient refrigerator was installed, and finally all phantom loads eliminated by the use of switched plug strips [33]. The potential of energy savings is large by using today's technologies while not making compromises in the residents' standard of living.

Energy-efficient appliances are more expensive than conventional ones today. Bringing down costs, however, is rather a question of production volume and economies of scales for a larger market than a question of higher production costs through technical complexity of energy-efficient appliances.

Load analyses are not as common with grid-connected houses than they are with remote houses. Electricity from the U.S. grid is exceptionally cheap. Therefore, electric customers usually do not pay much attention to potential savings through the installation of efficient appliances.

5.2.2. Social and behavioral aspects of energy consumption

Going back to the Middle Ages and reducing the current standard of living is a common fear of people living in industrialized countries when talking about reducing energy consumption. But using energy more efficiently does not necessarily mean a reduction in amenities, as using renewable resources does not mean going back to windmill and wood-stove technologies. Contemporary renewable energy technologies are sophisticated, and moderate modifications in social and behavioral energy consumption patterns can contribute significantly to developing a more sustained energy system.

The role of consumers in the end-use of energy has often been neglected by scientific and commercial research. Consumers' demand for energy was merely regarded as a function of technical or economic input variables. Social and behavioral research shows, however, that there is a vast energy saving potential through setting up incentives for consumers to use their energy efficiently. Assessing consumer behavior is a crucial prerequisite for changing our energy system to sustainability and for renewable resources being able to contribute a large part of the national and global energy demand.

Experiments with electricity customers indicated that consumers are indeed quite responsive to conservation incentives and disincentives. For example, unit metering of individual apartments instead of master metering the house as a whole, and thus charging the residents a fee that represented their actual use of energy lowered the use of energy more drastically than expected. Although the customers expected modest increases in their electricity bills only, they responded with virtually abandoning air-conditioning despite of hot summer temperatures [34].

5.3. Renewables for developing countries

The availability of renewable resources is an asset for many developing

countries and does not favor only the OPEC countries. High solar insolation or sufficient small-scale waterpower resources are the basis for sustained renewable electricity generation. Modern micro-hydro technologies do not need high altitudes or large amounts of water resources to generate electricity. They are not difficult to maintain and operate, and have life expectancies of decades. Micro hydropower often is the most cost-effective form of renewable power [35]. Solar cooking with efficient solar cookers that can be built by people of third world countries themselves can replace the burning of wood [36]. Solar hot water heating and photovoltaic electricity do not need any fossil fuels and can provide energy services at a lower cost than conventional heating systems or diesel generators. Since many developing countries still face a very low coverage of the central grid, photovoltaic electricity generation is cost effective in many locations already, but still struggles with the ecologically and economically problematic battery storage. Creating small-scale grids covering one or more villages with renewable energy power and installing fewer batteries while using a fossil fuel powered back-up generator seems economically and technically viable until new storage technologies emerge.

Although high-tech, renewable power generation is also socially friendly. A group of U.S. Indians who was known to refuse to get grid-connected accepted the installations of rooftop photovoltaic systems. They liked electricity and also accepted the newest technologies, the only thing they disliked was paying a monthly fee to a utility for electrical power from the grid [37]. Education, however, is an issue to be addressed in developing countries. To make renewable energy systems work properly over years, it requires information, training and maintenance of these systems.

Historically, utilities have preferred to invest in large central power stations but paid little attention to social impacts of their projects. For large hydropower projects, villages and communities had to move and social and ecological systems were distorted [38]. Multiple small-scale hydropower systems would not have had any of these negative affects on nature and human beings.

Regarding the advances in technology and economics of renewable power generation discussed above, developing countries and countries at the edge of industrialization do not have to follow the same path as today's industrialized countries did. The population of developing nations often grows at a high pace, and industrializing these countries the conventional way could lead to serious environmental and social problems [39]. Sustainable global development urges that developing countries do not follow the industrial nations' detour via fossil fuel power generation while abandoning traditional renewable technologies as well as neglecting modern high-tech renewable power generating options which provide clean and often cost-effective energy solutions.

6. Outlook: approaching sustainability

This paper showed the technical, economic, environmental, and social assets of

renewables. As the U.N Conference in Rio de Janeiro indicated, reaching a global sustainable economy will be hardly possible without increasing the share of renewables contributing to our energy basis. Although all human activities have started out using renewables, industrialized countries have shifted to an economy based on fossil fuels due to their cheap and abundant availability. The rapid pace of consuming natural resources and the emissions caused by burning fossil fuels changes the rules of development and the path that countries in transition to industrialization will be able and allowed to take, if we do not want to run the risk of global climate change.

Changing the structure of the energy sector is but a first step towards sustainability. Not only the production of energy, but also the use of energy has to change towards sustainability. Demand side management, efficiency improvements, and electric load reductions are important factors to address. Perhaps we will even have to change our consumption patterns from the credo of unlimited possibilities towards a more respectful and also restrictive use of the global resources. Alan Durning's book "How much is enough" reviews critically the habits of modern consumer societies [40].

Another aspect of a sustainable world economy is the production and consumption of commodities. The end-of-pipe principle of today's industrial production creates more waste and uses more resources than necessary. On the other hand, consumption patterns should shift towards the demand for ecological and socially benign products. An adequate consumer education is indispensable for industrialized as well as developing nations. Overcoming political, ethnical, and religious conflicts as well as stabilizing the world population are additional prerequisites for sustainability. Modern societies have experienced economic wars replacing conventional wars. A sustainable world, however, needs competition rather than confrontation to achieve an optimal allocation of resources.

Renewable electricity generation hence is but one aspect of a future-oriented global economy. Solar, wind, and waterpower can help us to use our limited natural resources in a responsible way and to improve the living conditions of current and future generations. Modern highly efficient technologies are available today but have to compete in an established energy system with numerous interest groups and a market with distorted price signals.

References

[1] Flavin Christopher, Lenssen Nicholas. Power surge. Guide to the coming energy revolution. Worldwatch Institute, Environmental Alert Series 1994.
[2] Bayless Charles E. Less is more: why gas turbines will transform electric utilities. Public Utilities Fortnightly (December 1, 1994): p. 24.
[3] Balzhiser RE. Technology — It's only begun to make a difference. The Electricity Journal 1996; 5.
[4] National Renewable Energy Laboratory (NREL). Study reveals top U.S. markets for grid-connected PV. Solar Industry Journal, Third Quarter 1996.
[5] Lamarre Leslie. The vision of distributed generation. EPRI Journal, April/May 1993.
[6] Howard Milton R (PanEnergy). Advancing electric competition by providing electric power

choice. Conference paper presented at the 17th Annual North American Conference of the USAEE/IAEE "(De) regulation of energy: intersecting business, economics and policy". Boston Park Plaza Hotel, October 27–30, 1996.
[7] Weiss Johnnie. Solar energy international. Personal communication at the Solar Energy Forum 1997, Washington D.C., Workshop Photovoltaic Design, April 21–24, 1997.
[8] Preston Georg T, Rastler Daniel M. Distributed generation: competitive threat or opportunity? Public Utilities Fortnightly, August 1996 – Davidson Keith G., Braun Gerald W. Thinking small: onsite power generation may soon be big. Public Utilities Fortnightly, July 1, 1993.
[9] Energy Information Administration / U.S. Department of Energy, Wind Energy Profile. Renewable Energy Annual 1996, Issued April 1997. Center for Renewable Energy and Sustainable Technology (CREST), The Sun's Joules. CD-ROM on Renewable Energy and the Environment, 1997.
[10] Paul Maycock for the Worldwatch Institute, World Price for Photovoltaic Modules, 1975–95. Database Diskette January 1997, File Solar.wk1.
[11] Energy Information Administration / U.S. Department of Energy (1996), The changing structure of the electric power industry: An update. Donald E. Osborn (Sacramento Municipal Utility District (SMUD) 1997), Commercialization of Utility PV Distributed Power Systems.
[12] Osborn Don. Electrifying Change. Solar Industry Journal, Third Quarter 1996.
[13] Wenger Howard, Hoff Tom (Pacific Energy Group), Osborn Donald E. (Sacramento Municipal Utility District), A case study of utility PV economics. Presented at the American Solar Energy Society's Solar '97 Conference, Washington D.C., April 1997.
[14] Hoff Thomas E. Integrating renewable energy technologies in the electric supply industry: A risk management approach. National Renewable Energy Laboratories (NREL), March 1997.
[15] Lovins Amory B, Yoon Daniel (Rocky Mountain Institute). Renewables in integrated energy systems. Keynote address to the ANZ Solar Energy Society Solar '93 Conference, Perth, W.A.
[16] CREST, op. cit. Ref. 9.
[17] International Energy Agency (IEA), World Energy Outlook, 1998 ed., pp. 83–121. IEA/OECD, Paris, 1998.
[18] DIE ZEIT #40, 30. September 1999, pp. 21–22. German Periodical.
[19] Gerhard Scherhorn, Personal Conversation, June 14, 1996. University of Hohenheim, Institute for Consumer Economics, Germany.
[20] Worldwatch Institute, Government research and development spending in International Energy Agency member countries. Database Diskette January 1997, File R and D.wk1.
[21] CREST, op. cit. Ref. 9.
[22] United Nations Organization, The Rio Declaration. Report of the United Nations Conference on Environment and Development. Rio de Janeiro, 3–14 June 1992.
[23] Worldwatch Institute, Gasoline Tax, Price, and Use, Selected Industrial Countries. Database Diskette January 1997, File Taxes.wk1.
[24] Energy Information Administration (EIA), U.S. Department of Energy (1993), The changing structure of the electric power industry, 1970–1991. Energy Information Administration (EIA), U.S. Department of Energy (1996). The changing structure of the electric power industry: An update.
[25] Fox-Penner Peter. Electric utility restructuring. A guide to the competitive era. Public utilities reports, Inc., Vienna, Virginia, 1997.
[26] Energy Information Administration / U.S. Department of Energy, Electricity Generation and Environmental Externalities: Case Studies. September 1995.
[27] Brennan Timothy J, Palmer Karen L et al. Shock to the system. Restructuring America's Electricity Industry. Resources for the future, Washington D.C., 1996.
[28] California Energy Commission (March 1997), Policy Report on AB 1890 Renewables Funding.
[29] Zucchet Michael J. Renewable resource electricity in the changing regulatory environment. Feature article in renewable energy annual 1995, Energy Information Administration / U.S. Department of Energy.
[30] Utility Photovoltaic Group (UPVG), Multi-utility market survey on "PV friendly" pricing reveals strong, positive reaction to PV. The UPVG Record, Fall 1996.

[31] Dar Vinod K. The search for consumer content in energy marketing and retailing. Public Utilities Fortnightly, September 15, 1996.

[32] Meier Alan, Wright Janice, Rosenfeld AH. Supplying energy through greater efficiency. The potential for conservation in California's residential sector. University of California Press.

[33] Root Benjamin. Doing a load analysis: the first step in system design. Home Power Magazine #58, April/May 1997.

[34] Lutzenhiser Loren, Washington State University, Social and behavioral aspects of energy use. Annual Reviews Energy Environment, 1993.

[35] Cunningham Paul, Atkinson Barbara. Micro hydropower in the nineties. Home Power Magazine #44, December 1994 / January 1995.

[36] Nichols C. Alan. Solar cooking basics. Home Power Magazine # 39, February / March 1994.

[37] Weiss Johnnie. Solar Energy International. Personal Communication at the Solar Energy Forum 1997, Washington D.C., Workshop Photovoltaic Design, April 21–24, 1997.

[38] Brennan Timothy J, Palmer Karen L. et al., 1996, op. cit.

[39] Repetto Robert (World Resources Institute 1994), The second India revisited: population, poverty, and environmental stress over two decades.

[40] Durning Alan. How much is enough? The consumer society and the future of the earth. Worldwatch Institute, Environmental Alert Series 1992.